

forward to Lisa
for email w/
permit limits

Technologies, Performance and Costs for Wastewater Nutrient Removal
Water Quality Control Division
September 2, 2010

use in comments
to CD - example
rationale

Introduction

The Water Quality Control Division (Division) is currently developing numeric nutrient criteria for streams and reservoirs in anticipation of a recommendation to the Water Quality Control Commission in January of 2011. The initial nutrient criteria proposed in February 2010 are presented in Table 1. Some of the criteria values are relatively low compared to the removal of nutrients that can be achieved by technologies commonly use to treat for nutrients. To assist in the understanding of the implication of the adoption of criteria at the proposed levels, in this report the Division has compiled information about phosphorus and nitrogen removal/reduction technologies for domestic wastewater treatment works. Specifically, this report evaluates previously published information on performance, availability, and cost of technologies that are likely to be applicable to publicly owned treatment works (POTWs) as well as other discharges of nutrients. This information was used to provide the Division's perspective on the treatment technologies, their expected performance, and costs in light of the proposed draft numeric criteria.

The Division has previously identified physical/chemical treatment (addition of a flocculant plus settling and filtration) as the current Limit of Technology (LOT) for phosphorus. In order to maintain consistency with commonly used industry terminology, this paper will use the term technologically achievable limit (TAL). The TAL can be defined as a lowest concentration that is a performance-based level which can be sustained for a period of time. (WEF, 2009). TAL depends on a number of factors including; type of technology, environmental factors, and operational capability/control.

The Division has identified the following five levels of nutrient removal and their expected performance is presented in Table 1: : Level -1 -this is achieved without any active nutrient removal technologies (secondary effluent); Level -2 - this is achieved with Biological Nutrient Removal (BNR) technologies (biological processes for N and P removal, without chemical addition); Level 3-- this level will require enhanced biological nutrient removal (ENR) technologies (ENR is accomplished through increasing the number of treatment units and/or by using other treatment-enhancing approaches); Level 4 - this is achieved with ENR and physical/chemical treatment technologies; and Level 5 - , this is achieved through the use of membrane processes such as ultrafiltration and reverse osmosis.

Table 1: Levels of Treatment and Colorado Proposed Nutrient Criteria for Rivers and Streams^b

Parameter	Typical Municipal Influent	Level 1	Level 2	Level 3	Level 4	Level 5	Colorado Proposed Criteria ^a	
							Cold Water Biota	Warm Water Biota
Total Phosphorus	4 to 8 mg/L	4 to 6 mg/L	1 mg/L	0.25 to 0.50 mg/L	0.05 mg/L	0.01 mg/L	0.09 mg/L	0.135 mg/L
Total Nitrogen	25 to 35 mg/L	20 to 30 mg/L	10 mg/L	4 to 6 mg/L	3.5 mg/L	1 mg/L	0.824 mg/L	1.316 mg/L
a. The “proposed criteria” represents the Division’s best estimate of the criteria at this point in the process.								

There are a number of domestic wastewater treatment plants in Colorado – e.g., those in the Dillon and Cherry Creek Reservoir basins – where levels less than 0.05 mg/L of TP through BNR and/or physical/chemical treatment have been achieved for many years (see Table 2). Moreover, for all dischargers, this level of treatment would be adequate to achieve attainment of water quality standards based on the current draft numerical phosphorus criteria that the Division identified in February.

The Division has proposed biological nutrient removal (BNR) as the appropriate treatment to achieve the TAL for nitrogen. This paper clarifies that the TAL for nitrogen will be based on Enhanced Nutrient Removal (ENR) technology. The Division believes that, unless there is a relatively high low-flow to design flow ratio coupled with upstream nitrogen concentrations lower than the standard, ENR treatment generally would not be adequate to achieve permit limits based on the draft numerical nitrogen criteria that the Division identified in February. Currently available information indicates that, based on the circumstances for many wastewater treatment facilities, attaining water quality standards based on the anticipated nitrogen criteria would require membrane treatment. This would likely include reverse osmosis, with substantial energy costs and a major cost/logistical challenge to dispose of the resulting brine.

Forms of Total Phosphorus and Total Nitrogen in Influent Domestic Wastewater

Common forms of phosphorus found in domestic wastewater include orthophosphates, polyphosphates and organic phosphates. The phosphorus in the influent can be classified as soluble or particulate, organic or inorganic, and biodegradable or unbiodegradable in the wastewater treatment facility (see Figure 1).

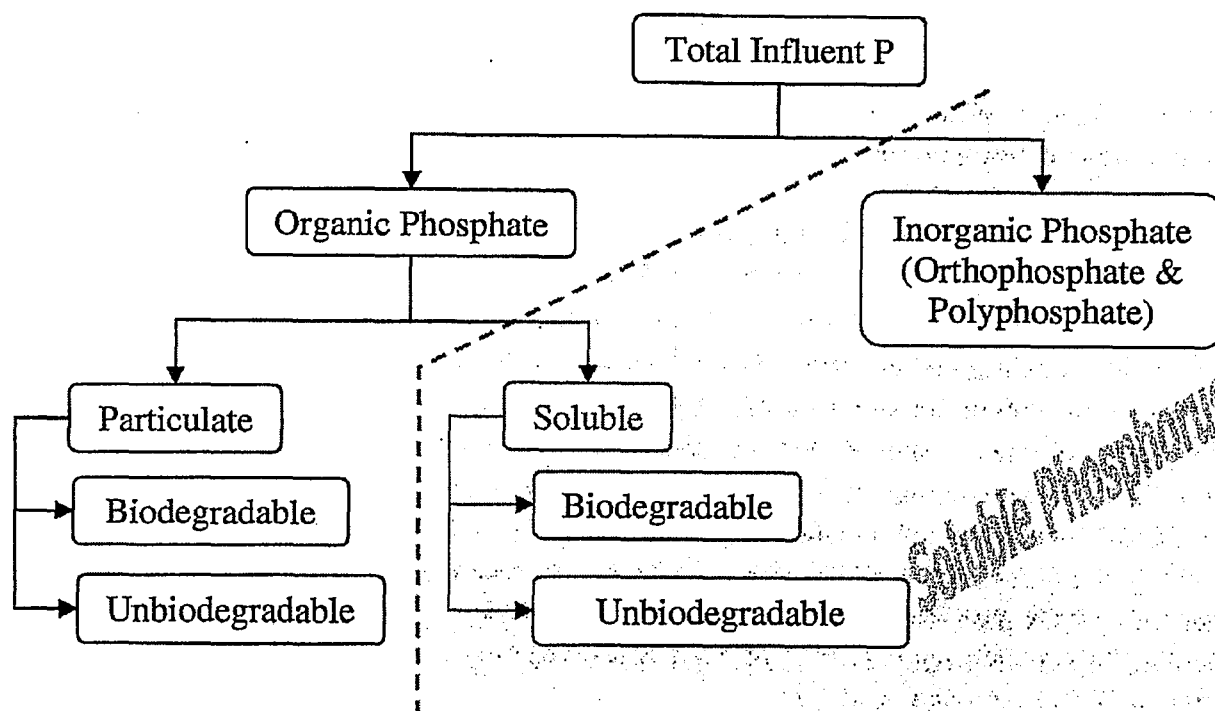


Figure 1: Forms of Total Phosphorus (WEF-MOP, April 2010)

Soluble-phosphorus that does not register as ortho-phosphate is non-reactive and passes through most systems since it cannot be treated chemically or biologically. Since permit limits would be based on total phosphorus it is important to differentiate between total, soluble and orthophosphates. Soluble inorganic phosphorus (predominately orthophosphates) and particulate organic phosphorus form the significant fractions in the wastewater (see Table 2).

TABLE 2 - OPERATIONAL DATA FROM COLORADO FACILITIES

Facility Name	Avg Influent Flow (MGD)	Total Phosphorus (mg/L)			Permit Limit (mg/L)	
		30 Day Avg	Min	Max	30 Day Avg	Daily Max
Pinery	0.644	0.027	0.015	0.048	0.05	-
Parker	2.913	0.26	0.015	0.040	0.05	-
Snake River	0.722	0.020	0.010	0.070	-	0.5
Frisco	0.743	0.064	0.014	.185	-	0.5

Notes

Based on 30-day average DMR data reported for the months from January 2006 to July 2010 - Number of data points =55

Common forms of nitrogen found in domestic wastewater include organic or inorganic, soluble or particulate, and biodegradable or recalcitrant (unbiodegradable). As nitrogen limits get more stringent, speciation of nitrogen is important to ensure that these limits can be reliably met. Soluble inorganic nitrogen (predominantly ammonia) and particulate organic nitrogen form the significant fractions in wastewater. Most of the organic nitrogen will be hydrolyzed to ammonia and removed through nitrification, but there exists a portion of unbiodegradable dissolved organic nitrogen (see Figure 2), or rDON, which is used to predict what total nitrogen (TN) concentration can be achieved through traditional biological and physical separation processes. rDON, which typically ranges from 0.5 to 1.5 mg/L, is a composite refractory material of mostly unknown composition, ranging from material that readily undergoes breakdown and becomes partially bioavailable to material that is highly resistant to breakdown. rDON is possibly composed of synthetic compounds, high molecular weight humic substances, and soluble microbial products from cell metabolism, decay and lysis. The bioavailability and fate of rDON is currently being researched extensively. Typical concentration ranges of nitrogen species in the effluent after BNR processes are: Ammonia-N-.50-1.5 mg/L; Nitrate-N-0.10 -0.50 mg/L; Particulate Organic Nitrogen <1.0 mg/L; and Dissolved Organic Nitrogen 1.0 to 1.5 mg/L, a significant portion of which is rDON.

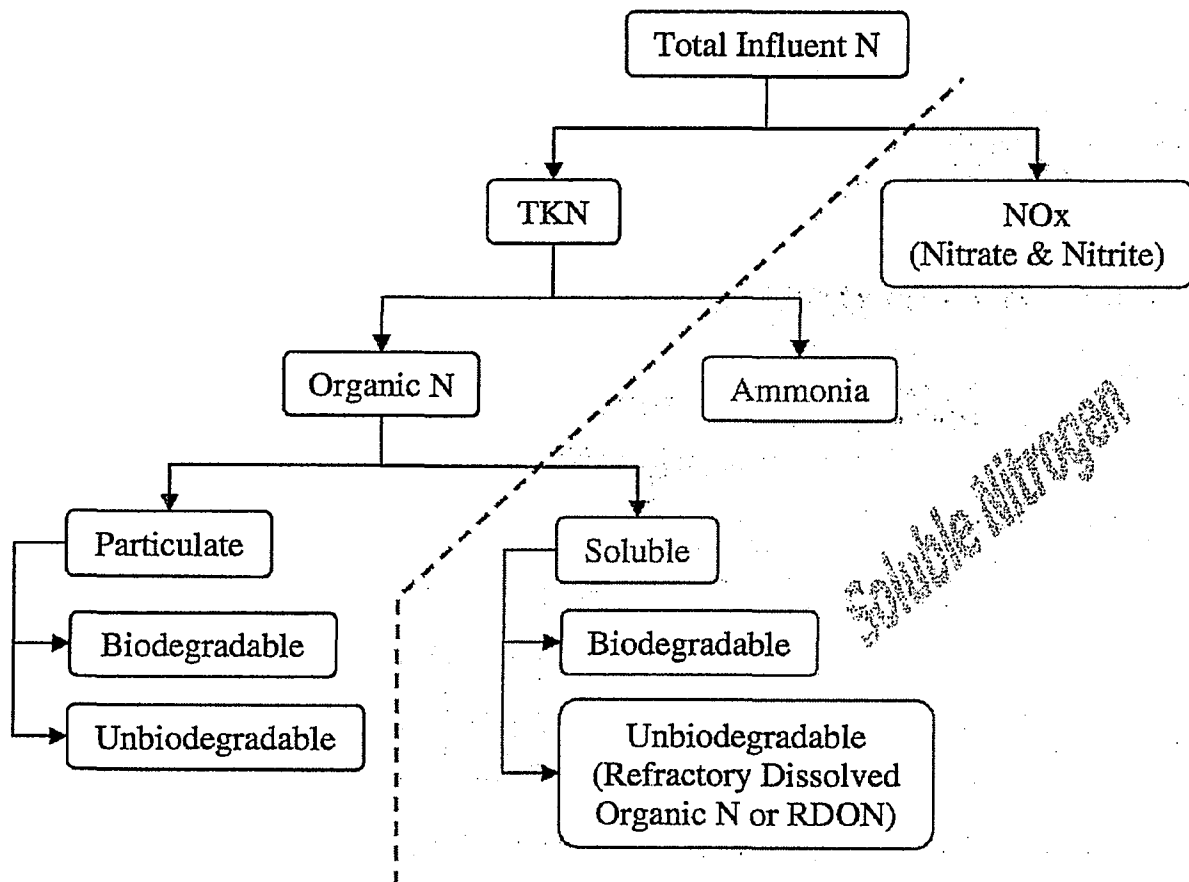


Figure 2: Forms of Total Nitrogen (WEF MOP- April 2010)

Typical concentration ranges of N & P in the influent domestic wastewater are presented in Table 3.

Table 3: Typical Concentration Ranges of N & P in Domestic Wastewater

	CONCENTRATION (mg/L as N or P)	
	<i>Soluble</i>	<i>Particulate</i>
<i>Nitrogen</i>		
Organic N	1 – 2	7 – 23
Ammonia/Ammonium	12 – 45	N/A
<i>Phosphorous</i>		
Organic P	<i>Negligible</i>	1 – 5
Inorganic P	3 – 10	N/A

Note: A significant fraction of the particulate Organic N is converted to Ammonia through hydrolysis and subsequent ammonification. The other fraction is typically removed through settling or agglomeration into biosolids.

Removal Mechanisms

Chemical phosphorus removal utilizes reactions between phosphorus in water and chemicals (usually multivalent metal ions) to form precipitates of sparingly soluble phosphates that can be subsequently removed from the liquid using a solids separation process (such as clarification and filtration). Commonly used chemicals include aluminum, ferric and calcium salts. Typically, total phosphorus levels of less than 0.05 mg/L can consistently be achieved with chemical addition and well-designed filtration facilities (Performance data for Cherry Creek and Dillon Treatment Plants) as shown in Table 2 in the previous section..

Biological phosphorus removal relies on phosphorus uptake by aerobic heterotrophs capable of storing orthophosphate in excess of the biological growth requirements. Biological phosphorus removal is accomplished through a combination of anaerobic/aerobic processes (see Figure 3)

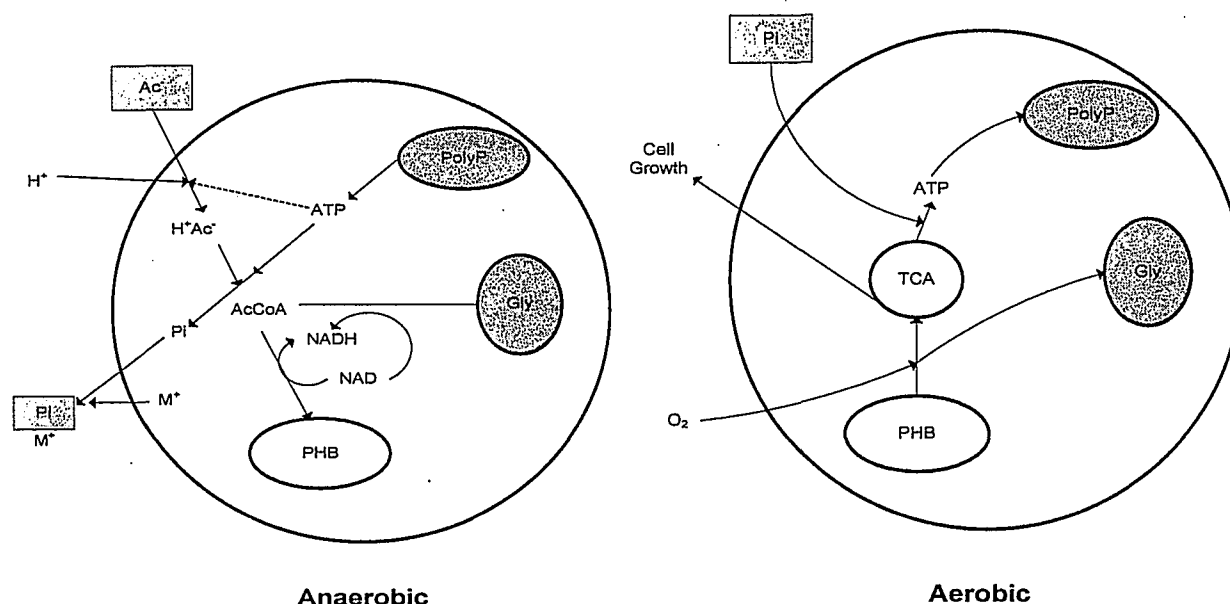


Figure 3: Biological Phosphorus Removal Mechanism

Under anaerobic conditions, Phosphate Accumulating Organisms (PAOs) convert readily available organic matter, Volatile Fatty Acids (VFAs), to carbon compounds called polyhydroxyalkanoates (PHAs). PAOs use energy generated through the breakdown of polyphosphate molecules to create PHAs. This breakdown results in the release of phosphorus. Under subsequent aerobic conditions in the treatment process, PAOs use the stored PHAs as an energy source to take up the phosphorus that was released in the anaerobic process. At the same time, the PAOs are able to excessively store phosphate as intracellular phosphate, leading to P removal from the bulk liquid phase via PAO cell removal in the waste activated sludge. Typically, biomass in the activated sludge process contains 1.5 -2.0 percent phosphorus based on dry weight, whereas with the enhanced biological phosphorus removal (EBPR) process the phosphorus content can be up to 20 – 30 percent of the biomass (M &E, 2003)

The objective of either biological phosphorus removal or chemical phosphorus removal is to convert soluble phosphorus into the particulate form so it can be removed through settling or filtration. The mechanisms involved in the removal of various phosphorus species and the associated technology limits are presented in Table 4.

Table 4: Total Phosphorus Removal Mechanisms

Form of Phosphorous	Common Removal Mechanism	Technology Limit (mg/L)
Soluble -P	Microbial uptake/chemical precipitation	0.1
Particulate -P	Solids Removal (clarification)	<0.05

Note : Typically Biological Phosphorus removal can achieve treatment to 0.2 to 0.3 mg/L TP and subsequent chemical precipitation, tertiary clarification and/or filtration can achieve treatment levels of < 0.05 mg/L TP.

Nitrogen can be removed physically or chemically by converting the nitrogen to nitrogen gas (break point chlorination; by stripping ammonia as gas (air stripping); by ion exchange; or by using membrane separation). Physical/chemical processes are typically not used as biological processes have been found to be the better technology for removing nutrients from wastewater. Biological nitrogen removal is achieved through a series of biochemical reactions that transform nitrogen from one form to the other. A fraction of the particulate organic fraction is converted to soluble biodegradable organic nitrogen (through hydrolysis). This is the nitrogen associated with amino acids and other soluble, nitrogen containing organic substrates. The soluble organic nitrogen is converted to ammonia-nitrogen through the process of ammonification. Almost all of the fraction of particulate organic nitrogen that does not undergo hydrolysis, including that associated with the total suspended solids is removed through clarification and filtration. Ammonia is then converted to nitrate through the process of nitrification under aerobic conditions by autotrophic microorganisms. Nitrate is used as an oxygen source under anoxic conditions by denitrifying organisms and, in the presence of a carbon source, is converted to nitrogen gas through a process called denitrification (see Figure 4). Biological processes that are not designed for nutrient removal will typically remove 7 to 10 percent of the nitrogen (on a VSS basis), as it is an essential nutrient for biological growth.

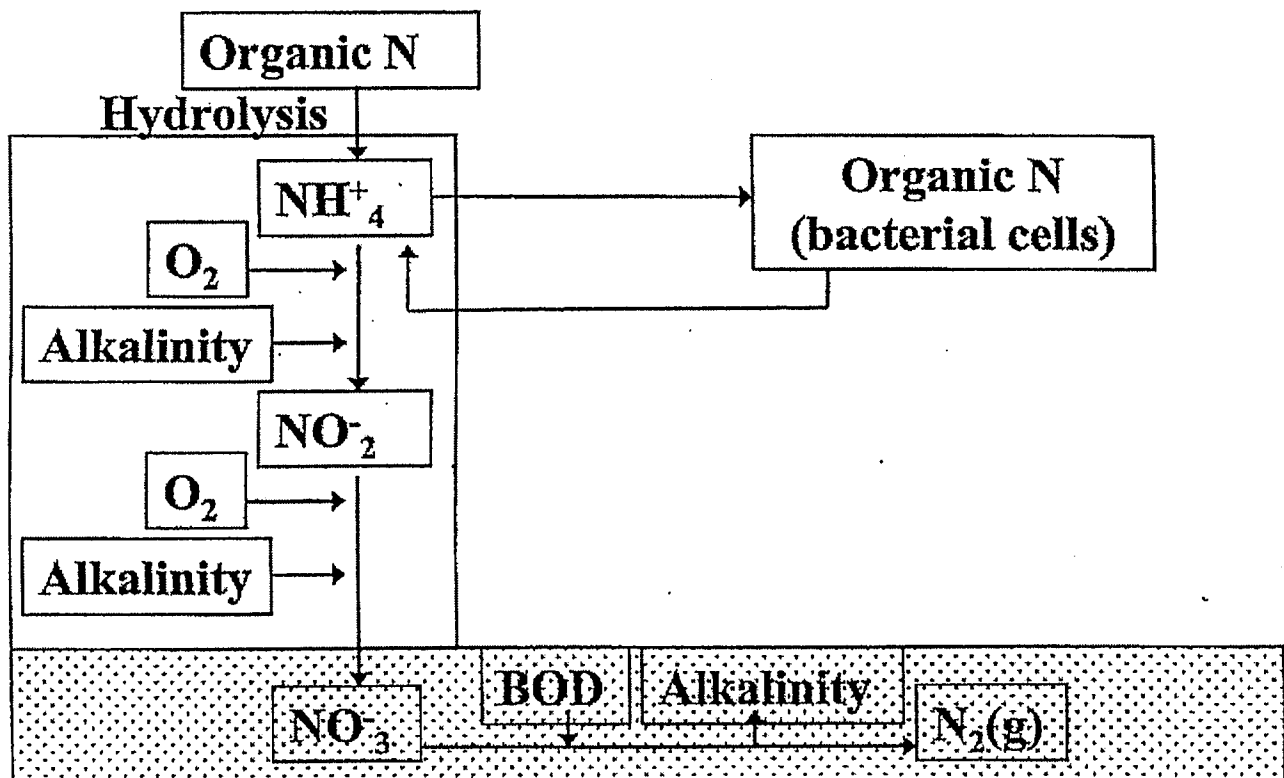


Figure 4: Nitrogen removal mechanism (Note: the dotted area represents anoxic condition and the rest of nitrogen removal mechanisms are performed under aerobic conditions)

The objective of biological nitrogen removal treatment processes is to convert soluble inorganic nitrogen (influent ammonia and ammonia from hydrolyzed organic nitrogen) to inert nitrogen gas through the aforementioned biological processes.

Additionally, particulate organic nitrogen can be partially removed through the physical separation process of clarification and virtually fully removed if filtration is added. The mechanisms involved in the removal of various nitrogen species and the associated technology limits are presented in Table 5.

Table 5: Total Nitrogen Removal Mechanisms (EPA, June, 2007)

Form of Nitrogen	Common Removal Mechanism	Technology Limit (mg/L)
Ammonia-N	<i>Nitrification</i>	< 0.5
Nitrate-N	<i>Denitrification</i>	1 – 2
Particulate organic-N	<i>Solid Separation</i>	< 1.0
Soluble organic-N	<i>None</i>	0.5 – 1.5

Removal Technologies

As stated earlier, phosphorus removal is accomplished by converting the soluble fraction into particulate phosphorus through the incorporation of the phosphorus in to the biomass or through precipitation as a metal salt and the subsequent removal of phosphorus through physical processes of clarification/settling and/or filtration to separate the solids (See Figure 5).

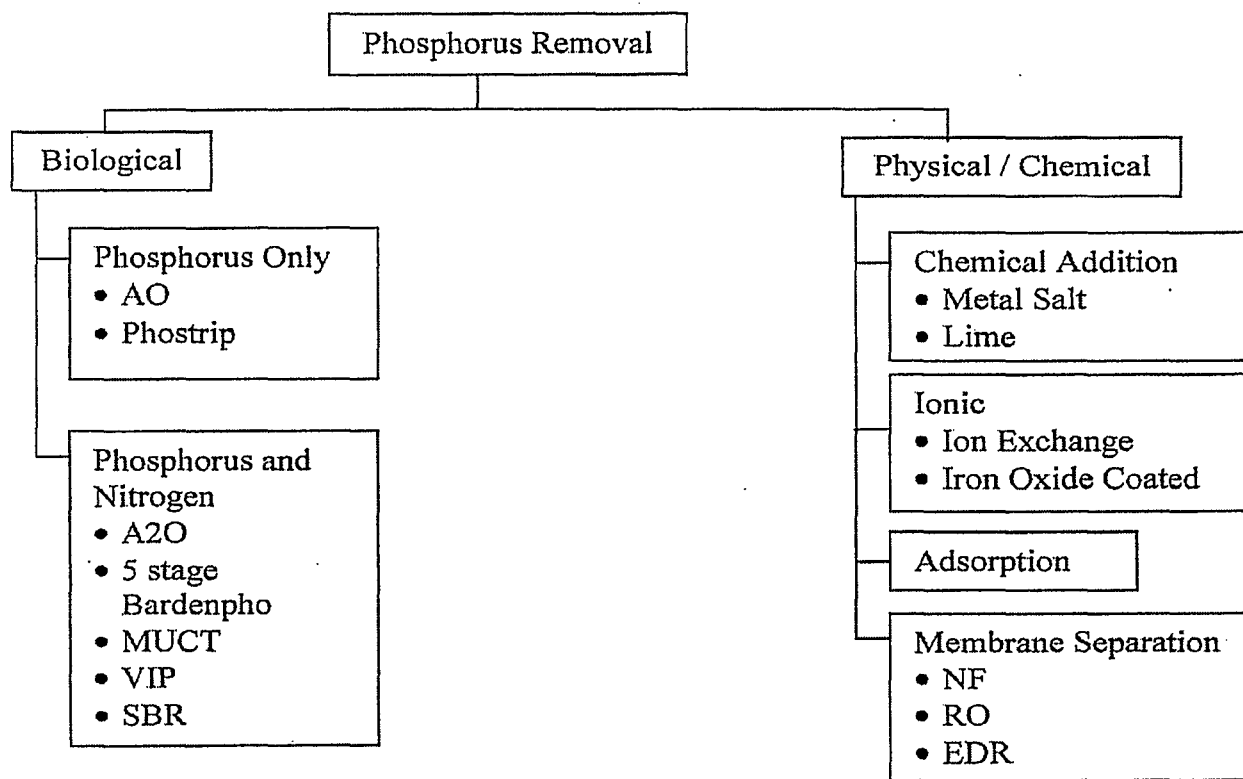


Figure 5: Phosphorus Removal Technologies

Biological phosphorus and nitrogen removal can be accomplished in the same treatment process by providing for various configurations of anaerobic/anoxic and aerobic environments.

Treatment configurations have been constructed in Colorado that have consistently achieved a monthly maximum of less than 0.05 mg/L TP. For example, the Pinery WWTF, a 2.0 MGD capacity plant, has been consistently achieving monthly averages of 0.02 to 0.03 mg/L for Total P. In general, plants relying on chemical addition and filtration for P removal outperform those that rely exclusively on biological P removal. Additionally, some plants with some form of tertiary clarification outperform those which have only effluent filters (WERF, 2009).

Biological nitrogen removal processes are prevalent because they are cost effective, environmentally beneficial and can be readily incorporated into the domestic wastewater treatment works which predominantly utilize biological processes for the treatment of domestic sewage. A number of modifications of the biological processes - suspended, fixed film, and hybrid (such as IFAS) - are available to treat to the TAL (See Figure 6). It has been observed that separate stage N plants - where carbon oxidation, nitrification and denitrification are accomplished in separate reactors - that typically use an outside carbon source such as methanol outperform combined N plants - where carbon oxidation, nitrification and denitrification are combined into a single process that uses carbon naturally developed in the wastewater. (WERF, 2009).

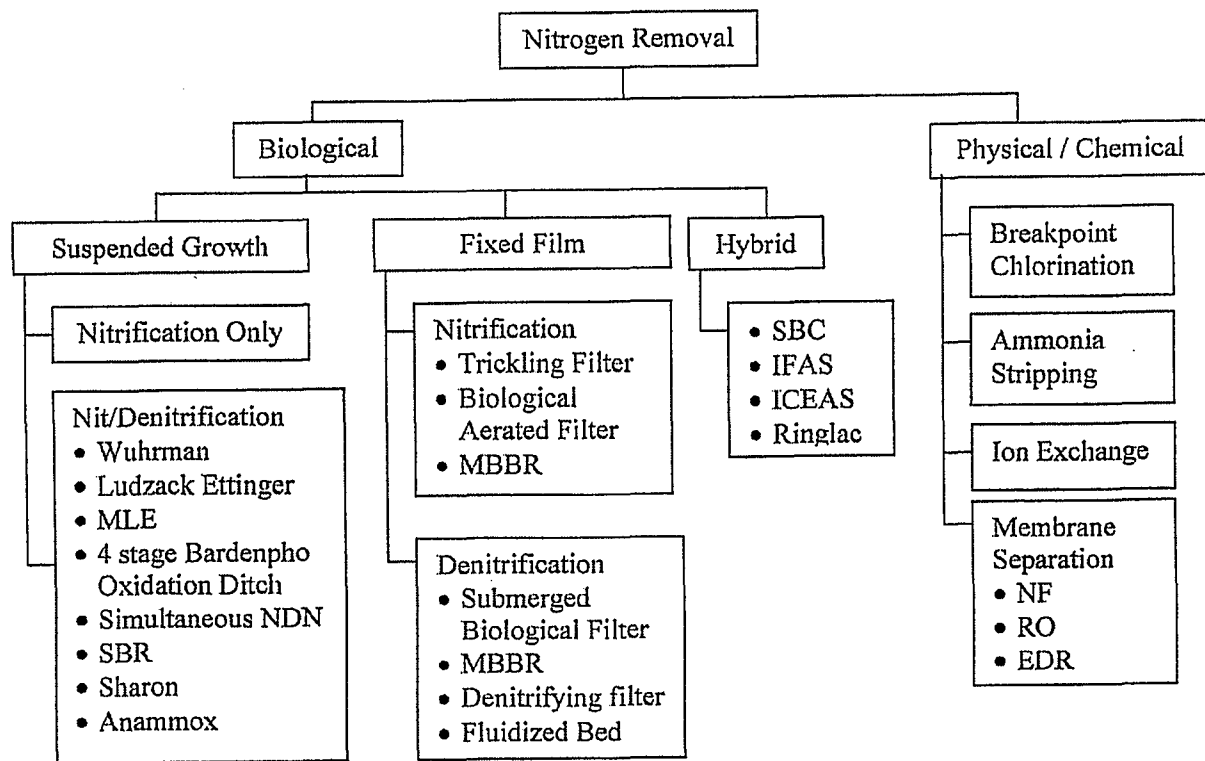


Figure 6 – Nitrogen Removal Technologies

Performance and Costs

The cost and performance information developed in the section is based on the compilation of data from a number of sources. The information provided here recognizes that costs vary widely, depending on a number of factors including target concentrations for phosphorus and nitrogen and suitability of the existing system for upgrades.

Additionally, information provided in an EPA document (URL provided below) was reviewed to assist the Division in estimating costs for various flow rates, target concentration limits and possible upgrade scenarios: The possible upgrades considered were -retrofitting existing facilities with additional piping and equipment; adding a new process technology to an existing treatment train; or expanding the existing facility with possibly an entirely new technology. EPA used CAPDETWorks software to estimate costs. A detailed description of the assumptions and the cost estimating methodology is presented in the EPA document (www.epa.gov/OWM/mtb/mnrt-volume1.pdf). The cost estimates provided in the EPA document are based on an Engineering News Record (ENR) Cost Index of 7910 (May 2007). The costs provided in this document are adjusted to reflect 2010 costs. Based on the May 2010 ENR Cost Index of 8761, the costs have been adjusted upwards by 10 percent. Additionally, preliminary treatment, primary treatment and sludge handling costs were not considered in the EPA cost estimates. Costs from two Colorado facilities are also provided in this analysis.

Retrofits

The treatment alternatives selected were deemed most likely to fit the retrofit option to be used at an existing facility because of foot print size, ease of installation in an operating facility, ability to meet treatment objectives and overall costs. Treatment alternatives for the following flow rates - 0.1 MGD, 0.5 MGD, 1 MGD, 5 MGD, and 10 MGD - were considered since this range covers most domestic wastewater treatment works. Limited cost data was available for flows of less than 1 MGD and greater than 10 MGD. Additionally, the available information supports alternatives based on TP limits of less than or equal to 0.1 mg/L and TN limits of 5 mg/L and 3 mg/L. The Division did identify a small amount of actual cost information for Colorado facilities treating TP to less than 0.05 mg/L. Limited cost data was available for a TN concentration of less than 3 mg/L and TP of less than 0.05 mg/L. Such levels of treatment that would be required to approach the level necessary to meet permit limits for total nitrogen that would be based on the draft February criteria for TN.

Retrofit-P removal Technologies – The following two options were considered for modifying or making additions to existing biological treatment facilities that would be required to accomplish phosphorus removal for cost estimating purposes:

Option A - Two-point Chemical addition- Alum addition at two points both upstream and downstream of an existing AS process, 0.05ppm target, sand filter down stream of secondary clarification; Lagoon systems can be modified to accommodate option A. The retrofit will typically include conversion of the polishing lagoon into a clarifier and chemical addition prior to the clarifier for flocculation to convert soluble-P into Particulate-P and to enhance settling of solids with filtration downstream of the clarifier to capture any unsettled solids (particulate-P). This retrofit should meet target limits of 0.05 mg/L Total P. However, this will require increased operator attention and skills and additional chemical requirements.

Option B – Biological Phosphorus Removal – by retrofitting an existing activated sludge treatment process with an A/O, by adding a fermenter to generate VFAs for biological phosphorus uptake, alum addition, and a sand filter to achieve the 0.05 ppm target. Option B cannot be implemented with a lagoon system because it requires an activated sludge process to be in place.

The capital costs (\$/gpd) for option A are presented in Table 6, below. It is the Division's opinion that both of these options will be able to meet target levels of less than or equal to 0.05 mg/L TP on a consistent basis. Meeting 0.05 mg/L TP or lower will somewhat increase chemical, operator and residuals management costs. Option B has higher capital costs ranging from 20 to 40 percent, across the flow rate considered, because of additional tankage for fermenters and processes compared to option B. However, the O & M costs for option B are about 40 to 50 percent lower than Option A, because of lower chemical costs. This is because a biological phosphorus process will typically reduce TP to about 0.2 to 0.3 mg/L, hence the subsequent chemical addition is considerably lower compared to option A. It is the Division's opinion that chemical addition is more reliable in meeting low phosphorus limits, when cost is

not a consideration. Biological phosphorus removal requires increased operator skills to meet treatment objectives and by itself will not be able to meet limits less than 0.1 mg/L without chemical addition and filtration or other tertiary treatment options. Hence, biological phosphorus removal is not recommended for small systems where operator attention may not be at the highest level

A type of Option A treatment alternative is in place at both the Pinery and Parker WWTFs. The treatment train includes biological phosphorus removal, alum addition and filtration and produce effluent TP concentrations as shown in Table 2, above.

Retrofit-N removal Technologies – The Division considered the following three options for modifying or making additions to existing biological treatment facilities that would be required to accomplish nitrogen removal for cost estimating purposes. The target TN concentration was assumed to be 3 mg/L. It is assumed that high efficiency nitrification and denitrification processes will produce an effluent of 3.5 mg/L TN or less with ammonia-N concentration of 0.5 mg/L or less, nitrate-N concentration of 1 mg/L or less ; particulate organic nitrogen concentration of 1.0 mg/L or less and dissolved organic nitrogen of 0.5 - 1.5 mg/L or less of which a significant portion of it is composed of rDON and can be achieved by using Level 4 treatment as described in Table 1.

Option A – Installation of additional tank capacity at an AS facility to allow sufficient residence time in an anoxic zone to accomplish denitrification.

Option B – Retrofitting existing AS as a modified Lutzak-Ettinger (MLE) process with anoxic/aerobic zones and internal recirculation.

Option C – Installation of a denitrifying filter with methanol addition.

Nitrogen removal using BNR processes in lagoon systems is not readily implementable because it would require the lagoons to be converted into mechanical plants.

Based on the cost data, summarized in Table 6, Option A has the lowest capital cost (because installation of an additional tank to the existing oxidation ditch) and Option C has the highest operating cost because of costs associated with methanol addition. . The lowest cost option requires a larger foot print whereas the highest cost option requires a smaller foot print.

It is the Division's opinion that all the three options will be able to meet target levels of 3.0 mg/L TN on a consistent basis using biological processes. Target levels of less than 3.0 mg/L would require additional physical/chemical processes. It is the Division's opinion that to meet a target level of less than 1 mg/L will require advance treatment such as reverse osmosis. Cost estimate for retrofitting a 16 MGD plant in California to meet 1 mg/L TN was estimated at \$5.72/gpd capacity, which is over a tenfold increase in cost compared to option A.

Retrofit-N plus P removal Technologies- a combination of BNR to achieve nitrogen removal and some phosphorus removal plus chemical phosphorus removal would be used to reach target

Table 6 Cost Summary for Facility Retrofits for N and P Removal Technologies:

<i>Flow</i>	<i>0.1 MGD</i>	<i>0.5 MGD</i>	<i>1.0 MGD</i>	<i>5 MGD</i>	<i>10 MGD</i>	<i>30 MGD</i>
Facility Retrofits for Nitrogen and Phosphorus Removal						
Capital Costs	\$8.5/gpd ^a	-	\$2.20- \$2.53 / gpd ^c	\$1.38- \$1.67 / gpd ^c	\$1.00- \$1.43 / gpd ^c	
O&M Costs	\$0.94/ gpd ^a	-	\$335- \$375/MG Treated ^c	\$275 – \$310/ MG Treated ^c	\$220 – \$285/ MG Treated ^c	
Facility Retrofits for Nitrogen Removal (TN-3.5 mg/L)						
Capital Costs	\$3.12/gpd ^b	-	\$0.66- \$1.48 / gpd ^c	\$0.56- \$1.01 / gpd ^c	\$0.66- \$1.48 / gpd ^c	0.88/gpd ^b
O&M Costs	\$23,000 Annual Cost ^b	-	\$110- \$484/MG Treated ^c	\$56- \$341 /MG Treated ^c	\$55-165 / MG Treated ^c	\$84,000 Annual Cost ^b -
Facility Retrofits for Phosphorus Removal (TP <0.1 mg/L)						
Capital Costs	\$3.88/gpd ^b	-	\$0.85- \$1.00 / gpd ^c	\$0.50- \$0.64 / gpd ^c	\$0.32- \$0.53 / gpd ^c	0.61/gpd ^b -
O&M Costs	\$54,000 AnnualCost ^b	-	\$191 - \$303/MG Treated ^c	\$127- \$248 /MG Treated ^c	\$121 - 248/ MG Treated ^c	\$3.06 Million- AnnualCost ^b
<p>a. EPA Study June 2007.</p> <p>b. Chesapeake Bay Study (cost range to meet TN of 3 mg/L, TP < 0.1 mg/L)</p> <p>c. EPA Study Sept 2008.</p> <p>d. Actual Colorado Facility: Parker Water and Sanitation District. Cost for building 2 MGD plant to treat TP<0.05 mg/L, TIN, 5 mg/L.</p> <p>e. Actual Colorado Facility: Pinery Water and Sanitation District. Cost for upgrade existing plant from one (1) to two (2) MGD to meet TP <0.05 mg/L and TN of 5 mg/L.</p>						

levels of 3 mg/L TN and 0.1 mg/L of TP. The following two options, which include tertiary filters, were considered for cost estimating purposes.

Option A – Oxidation ditch retrofitted with additional tanks for denitrification and fermentation, with one-point alum addition for phosphorus removal, plus a tertiary clarifier and a tertiary sand filter.

Option B – Conversion of an AS system to a 5-stage Bardenpho (suspended growth process with alternating anoxic/aerobic/anoxic/aerobic stages and an initial anaerobic zone to remove both Total N and P) with chemical addition for phosphorus removal and a tertiary filter.

The capital costs (\$/gpd) for option A are also presented in Table 6. It is the Division's opinion that both these options will be able to meet target levels of 0.1 or less mg/L Total P and 3.5 mg/L for TN on a consistent basis. Option B has higher capital cost and O & M costs compared to option A. A summary of the costs is presented in Table 6.

Small Systems

A cost and performance study for small systems (less than 0.1 MGD) was performed by Foess et al (1998). These costs were modified to reflect costs (in dollars) from the year 2006 by the EPA for BNR processes for nitrogen removal (EPA 2007). It was observed that BNR systems for smaller facilities are usually pre-engineered factory or field-assembled package systems. In most cases, chemical phosphorus removal was preferred for small systems because of a lack of operational oversight to achieve low biological phosphorus levels. Typical effluent TN concentrations ranged from 6 mg/L to 10 mg/L. To achieve lower TN concentrations would require effluent polishing filters. Average construction costs for new plants ranged from \$70.97/gpd for a 4,000 gpd system to \$8.50/gpd for a 100,000 gpd system. The associated O&M costs for the 4,000 gpd and 100,000 gpd systems were estimated at \$7.86/gpd and 0.94/gpd, respectively. Average construction costs for retrofits ranged from \$16.25/gpd for a 4,000gpd system to \$1.47/gpd for a 100,000 gpd system. The associated O&M costs for the 4,000 gpd and 100,000 gpd systems were estimated at \$3.71/gpd and 0.25/gpd, respectively. These costs are summarized in Table 7.

Table 7 - BNR UNIT COSTS FOR SMALL SYSTEMS (Cost in 2006 \$)

Component	4,000 gpd	10,000 gpd	25,000 gpd	50,000 gpd	100,000 gpd
New Plants					
Construction	\$70.97/gpd	\$34.66/gpd	\$19.34/gpd	\$14.58/gpd	\$8.50/gpd
O&M	\$7.86/gpd	\$3.70/gpd	\$2.10/gpd	\$1.43/gpd	\$0.94/gpd
Retrofits					
Construction	\$16.25/gpd	\$7.25/gpd	\$3.72/gpd	\$2.20/gpd	\$1.47/gpd
O&M	\$3.71/gpd	\$1.54/gpd	\$0.67/gpd	\$0.44/gpd	\$0.25/gpd

Source: Foess *et al.* 1998 Construction costs updated from 1998 dollars using the ENR construction cost index; O&M costs updated from 1998 dollars using the Bureau of Labor Statistics consumer cost index.

Summary

Based on the information presented in this report the Division draws the following conclusions:

1. Nutrient removal technologies to retrofit existing plants to meet target limits of less than 0.05 TP and 5 mg/L TN on a consistent basis are currently available and are in operation in Colorado.
2. Chemical addition followed by filtration is a preferred treatment alternative to remove Total P for most systems to levels less than or equal to 0.05 mg/l. The operational costs are typically higher compared to biological phosphorus removal plus chemical addition because of the additional chemical costs.

3. The predominant nitrogen reduction technologies focus on enhancement to secondary biological treatment. In general, BNR processes reduce TN to 6 to 10 mg/L and ENR refines BNR to achieve TN of 3.5 mg/L. BNR processes reduce TP to 1 to 3 mg/L and ENR refines BNR to achieve a TP of 0.3 mg/L.
4. In a situation where there is little dilution or high upstream TN values, the allowable discharge concentration would be at or near the proposed nutrient criteria for TN of 0.824 to 1.316mg/L TN which would require membrane processes such as reverse osmosis to remove the soluble recalcitrant dissolved organic nitrogen. This would be a very costly option (at least a ten-fold increase in costs compared to treatment technologies that remove nitrogen to 3.0 mg/L TN).